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BIOMEDICAL AND BEHAVIORAL SCIENCES

No. 45

EFFECTS OF NONIONIZING ELECTROMAGNETIC RADIATION

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CELLULAR AND MOLECULAR EFFECTS AND THE MECHANISM OF ACTION OF MICROWAVE ELECTROMAGNETIC FIELDS ON BIOLOGICAL SYSTEMS

Moscow ELEKTRONNAYA OBRABOTKA MATERIALOV in Russian No 3, 1978, pp 59-65

[Article by S. L. Arber]

[Text] Systematic research on interaction of microwave (MW) electromagnetic fields (EMF) with living organisms of the most diverse species--from Protozoa to Man--has been going on for more than 3 decades. During this time a considerable amount of experimental material has been accumulated attesting to the diverse effects of MW on the human and animal body (1-3). The obtained data have helped to solve many hygienic and clinical problems associated with the effect of this factor, but the biophysical mechanisms behind the biological action of MW, which are of considerable interest to not just theoretical biology alone, still remain unclear.

Research on the role of EMF in evolution of living nature, on the effect of solar activity on the Earth's biosphere, and on providing protection to spacecraft crews against their own and relict radio emissions, and development of the use of MW in medicine and agriculture are associated with progress in research on the mechanisms behind the biological action of MW.

It is entirely understandable that to solve this problem, we must conduct modeling research on isolated cells, subcellular structures, and solutions of various biomacromolecules. This article is devoted to this research.

Effects and Mechanisms at the Cellular Level

Using the classification in (1), we can subdivide the diversity of the effects of an EMF on cells into two groups with the following characteristics: 1) A particular orientation, alignment into a chain, or directed movement of unicellular animals (electromechanical effects); 2) change in physiological functions.

It is now clear that effects in the first group can be explained by the premises of classical electrodynamics, and a knowledge of variables such as field intensity, dielectric permeability of particles and the medium, particle geometry, and so on is quite sufficient to predict their behavior in an EMF (4-10). Experiments on the action of 20 and 50 MHz EMF on killed unicellular organisms (11) once again demonstrated that transverse orientation of elongated particles in an EMF is not the product of specific action of waves, inasmuch as the organisms were dead in this case.

It is also clear that these effects do not apparently have biological significance. This was demonstrated for one of the best known and most highly researched phenomena of this group--formation of pearl chains. The basic characteristics of this phenomenon are as follows: 1) Alignment into a chain occurs only when the field intensity is above a threshold value; 2) the threshold value of the field does not depend on frequency, and it is inversely proportional to particle radius; 3) the time constant for chain formation is proportional to the cube of particle radius, and it is inversely proportional to the square of field intensity.

The threshold of chain formation for particles with a 10 μ radius corresponds to a field intensity on the order of 2.5 v/cm. When the power flux density is about 10 vm/cm^2, the field intensity in tissues is less than 1 v/cm, and thus only particles with a radius greater than 10 μ can form chains in the presence of these field densities. Considering that the time constant for formation of strands by particles less than 10 μ is significantly greater than the time of medium heating, assuming that conventional radar devices are being employed, and thus there are no freely rotating particles greater than 10 μ in tissues, the conclusion is made (12) that this effect does not have biological significance.

Mechanisms in the second group are associated with the action of an EMF on subcellular structures and macromolecules. It has been demonstrated (13-15) that cells absorb MW of particular frequencies (the millimeter range) corresponding to the absorption bands of cellular components. Absorbed energy alters metabolic and biosynthetic processes and retards cell growth. However, we should point out work (16) in which the effects described in (13,14) were not observed at the same frequencies. RNA- and DNA-containing viruses exposed to radiation in the same frequency range experienced a decline in their infectious activity (17), while irradiation of the *Drosophila* imago prior to mating caused change in fertility and viability (18). Inhibition of growth of bacterial cultures and change in phagocytic activity and protein biosynthesis were noted in (1,19,20)(the centimeter range). Ultrastructural changes in cells are cited in (21,22).

It follows from the above that effects in the first group most likely do not have biological significance, while mechanisms in the second group should be sought at the molecular level.

Effects and Mechanisms at Subcellular Level

In 1969 Schwan (23) theoretically demonstrated that any voltage arising on a cell membrane as a result of rectification of a superhigh frequency (SHF) field at a power flux density of about 10 mw/cm^2 would be several orders of magnitude less than the resting potential and, consequently, it cannot affect the state of a nerve cell. At the same time the few modeling studies that have been performed on giant neurons of mollusks and the medicinal leech (24-27) revealed that MW alter the membrane potential of nerve cells and their background activity.

The effect of an MW (27-3,000 MHz) on permeability of erythrocytes was studied in another recently completed group of works (28-35), also small. In these works, except for (35), it was found that a field in this range increases the concentration of intracellular sodium and decreases the concentration of intracellular potassium, as well as causing emergence of hemoglobin from cells. Granulocytes were observed to release lysosomal enzymes (33,34). The authors of these communications explain changes in ion transport across a membrane in different ways--from action of the field on water in hydrate radicals in the membrane (29) to changes in energy metabolism arising as a result of conformational transitions in the cell's macromolecular complexes (32), passive permeability, and the sodium-potassium pump (28,31,33).

Thus what is common to these two groups of works is an increase in membrane ion permeability in response to MW, which is obviously a manifestation of the cell's nonspecific reaction to MW. The explanation for this effect must be sought at the molecular level.

In fact, it is commonly accepted that the permeability of a membrane to a given ion is a function of the ion's mobility in the membrane and of the coefficient of this ion's distribution between the solution and the membrane (36). In turn, the distribution coefficient depends on electrostatic interaction between the ion and ligand groups on the membrane, and on steric correspondence between the ion and a pore (the three-dimensional arrangement of ligand groups, and so on). Assuming, in a linear approximation, that ion mobility within a membrane is independent of an MW field (the intensity of the electric field at the membrane is on the order of 10^7 v/m, while the intensity of the MW field's electric component is on the order of 10^4 v/m), we arrive at the need for examining molecular mechanisms at the membrane-solution interface. That this is necessary is also indicated by change in electrophoretic mobility of cells and colloids in response to irradiation (37-39).

We should also point out that the effect of MW on substrate oxidation, electron transport, oxidative phosphorylation, and calcium transport has been studied on isolated mitochondria (40,41). Changes were not revealed in the course of these processes.

Effects and Mechanisms at the Molecular Level

Leaving aside dielectric saturation (it requires an electric field with a very high intensity, a minimum of several kilovolts per centimeter (42,43), and thus it could hardly be interesting in relation to the problem here), we will examine a number of works in which the effect of an SHF field on the activity of various enzymes was studied (44-53). Thus Vogelhut (44) noted change in the reaction rate when a solution of lysozyme and its substrate was irradiated by a 10,000 MHz SHF field, while changes in the activity of lysozyme and trypsin were not revealed in response to a 2,450 MHz field (45). Changes in enzyme activity were not noted in studies on cholinesterase and aldolase at an irradiation frequency of 3,000 MHz (46), on dehydrogenase at 2,800 MHz (47), and on malate dehydrogenase, alkaline phosphatase, and others at 10-12, 700, and 2,000-2,600 MHz (48). Nor were changes observed in reaction rate in research on a hydrogen peroxide-catalase system in an SHF field (49), while changes were noted in a low frequency field (27 MHz) (50). A significant decline in the ATP-ase activity of actomyosin at 350 MHz (51) and of myosin at 2,400 MHz (52) was established. Nor did trypsin change its activity at this frequency (52), while peroxidase activity changed (2,450 MHz) (53). The authors of works in which changes in enzymatic activity were noted suggested, as the mechanisms, structural alterations of water (51) or breaking of hydrogen, hydrophobic, or covalent bonds (52). It would be interesting to note that basically in all of these experiments, enzymatic activity either remained unchanged or decreased (in most cases the systems were under thermostatic control).

On this basis unbalanced thermodynamics were employed (54) to demonstrate that this retardation of chemical reactions could be explained by disturbance, in an EMF, of the three-dimensional orientation of polar groups in the enzyme's active center (for completion of the enzymatic process, the rotating degrees of freedom of reacting groups must be "frozen," and an EMF hinders this). It is also clear from (54) that the kinetics of the enzymatic reaction do not change in an EMF when the active centers of the molecules do not contain catalytic polar groups.

Closely associated with this research are studies (55-57) performed on hemoglobin which, not being an enzyme, can serve, as we know, as an enzyme model. The effect studied in (55-57) involves strengthening the bonds between the heme and protein (weakening the bonds between oxygen and the iron atom) by irradiating aqueous solutions of hemoglobin with millimeter waves, which can be interpreted as reducing the rate of transformation of hemoglobin from its oxi-state to its meta-state. The hypothesized mechanism is associated with rotating and rocking distal histidine (a polar amino acid residue) in the macromolecule's active center. Strengthening of the bond between the heme and the protein was confirmed in (58) by γ-resonance spectroscopy.

The primary mechanism behind the effects described above is not entirely clear from an energetic standpoint, inasmuch as the energy of thermal movement at room temperature (0.026 ev) exceeds the energy of a quantum of an MW field (10^{-4} ev at 3 GHz) by about two orders of magnitude (not to mention the relatively low activation energies for rotation of the protein's polar molecules (0.04-0.4 ev)), breaking of a hydrogen bond (0.08-0.2 ev), and hydrophobic interactions (0.008-0.06 ev). Of course the activation energy for rotation of polar groups in proteins may be lower due to a reduction in dipole-dipole interaction (nonpolar encirclement of the polar group), growth in mobility owing to a decrease in nondipole intramolecular interaction, and growth in molecule flexibility (59). In addition, resonant absorption is possible in polymers beginning with frequencies of 10^{10}-10^{11} Hz. Although Schwan (60) believes that the probability of resonance is low due to the high viscosity of an aqueous medium, this obviously does not pertain to hydrophobic areas of a macromolecule containing polar groups within itself.

It should also be emphasized that in this case we are possibly dealing with an example of the reaction capability of molecules being influenced significantly by weak intra- and intermolecular interactions, the energy of which is low as compared to bond energy and even to kT (61).

A large number of various quantum resonances, the frequencies of which are in the MW range, are known in physics. To observe them, however, in addition to an MW field we would need intense constant electric and magnetic fields that separate the system's inherent levels such that the frequency of transitions between them corresponds to the MW. In a cell, such fields (electric) exist only on the membrane. In this connection we should make mention of (62) which discusses the mechanism of excitation of a nerve by a low intensity EMF, on the basis of a hypothesis that a layer of dipoles forming a two-level system is located on both surfaces of the membrane of an axon. The frequency of the system's transitions corresponds to the MW range. However, this quantum model of microwave excitation of a nerve is limited in the sense that the action of the field can cause only its excitation (the levels must be inverted for an inhibitory effect). Incidentally, observation of MW radiation from such a system should be possible, but reports of this have not as yet appeared (only infrared radiation has been reported (63)).

One of the most natural ideas that could be placed at the basis of the mechanism behind interaction of a low intensity EMF and a biological system is apparently cooperativeness of processes proceeding on membrane surfaces (64,65). A perturbation sensed at one point can trigger conformational transformations of a membrane's macromolecules significant distances away, eliciting changes in cell functions. It should not be thought that cooperativeness means an instantaneous response of the system to an external effect, as might appear from the abruptness of experimental curves of phasal transitions. The kinetics of the process must be sufficiently slow (66) (see (67) for another hypothesized collective property of ensembles of biomacromolecules--coherent electric dipole oscillations, the frequency of which is 10^{11} Hz).

It has also been hypothesized (68) that the high sensitivity of biological objects to EMF can be explained only on the basis of presence superconductivity in biological systems. This idea is based on theoretical predictions of high-temperature superconductivity in laminated and thread-like structures (69,70) (a recent review of high-temperature superconductivity can be found in (71)), and on studies indicating indirectly that biomacromolecules can have superconductivity at room temperature (72,73).

In addition research conducted with an Al-C-Al "sandwich" resulted in recording of a volt-ampere characteristic in an MW field similar to that which is obtained in Josephson contacts at low temperatures. The necessity of such a hypothesis can be explained by the extremely high sensitivity of these contacts to MW irradiation (on the order of 10^{-13} w/cm^2).

Several ways for increasing the temperature of transitions have been noted to date, to include creation of special thread-like and laminated structures and placement of the system into an unbalanced state with the help of external fields (71). The latter case applies only to substances exhibiting equilibrium superconductivity. At the same time it is possible that an SHF field can produce a superconductive state in biomolecular structures similar to Little's hypothetical molecule (70) by inducing oscillations in side groups and causing, as a consequence, interaction between electrons moving in the main chain. In this case field absorption would depend on resonant processes in these groups, and the created superconductivity would interfere with the functions of molecular ensembles.

The high sensitivity of biological systems to EMF can also be examined from the positions of the theory of oscillation synchronization (75), from which it follows that two self-oscillating systems invariably undergo synchronization when an association exists between them, no matter how small, if the difference between their partial frequencies is sufficiently small. Thus MW radiation of even sufficiently low power would be perceived by the system, given that its frequency is close to the partial frequency of the object. Only the time required to establish synchronization is important in this case. It should be noted that Viner (76) hypothesized that the specificity of a macromolecule is the product of the frequency structure of its molecular emissions, a significant part of which might be in the infrared range and lower. It was suggested that this hypothesis could be tested by studying the absorption and emission spectrums of viruses and then exposing them to these frequencies. Work (13) was apparently completed in indirect compliance with this rule (see the section on cellular effects). In regard to enzymes, it is not necessary for their activity to change at all frequencies of the absorption spectrum; thus change should occur in relation to frequencies corresponding to active centers (77).

Summarizing the molecular effects examined above, we can say that despite many uncertainties concerning this problem, the biological effects of MW are doubtlessly associated with the molecular level of organization of living systems.

Conditions Necessary for Observation of the Biological Effects of Microwaves

An examination of the methods (assuming they are described in detail) used in research on the action of MW on cellular and molecular structures would permit us to note the following typical features. Some particular effect is observed only when, during irradiation, constant temperature is maintained and the irradiation time is on the order of dozens of minutes and more (17,18,20,22,27,28,30,31,34,39,51,53,56,57,78,79,80,81). In cases where irradiation time was on the order of minutes and lower (41, 47,82-86) or where the temperature increase of the object following irradiation was in the degrees and higher (45,47,48,82), the effect was absent (exceptions in relation to irradiation time can be found in (24-26)). We should also cite studies (16,35,49,62,87) performed with the goal of testing (13,14,33); an effect was not observed (16,35) despite compliance with the necessary conditions. The negative result in (16,35) is apparently not associated with the requirement of fully identical research conditions, and an explanation for (49,52,87) can probably be found on the basis of the results of (54). The following question arises: Why is compliance with the conditions indicated above necessary (though not always sufficient) to permit observation of an effect? Clearly the effect's arisal is associated with some particular process requiring a greater irradiation time. It would be difficult to name this process today. Perhaps it involves cooperativeness or synchronization of oscillations, or a certain type of pumping process or, finally, high-temperature superconductivity. It is interesting that long irradiation times were also noted in (74). Apparently such a long time is needed so that the field could manage to produce a certain three-dimensional and temporal order in the biological system. Absence of an effect when the object undergoes heating indicated that a rise in temperature significantly affects this process, responsible for change in the functional properties of biological structures. We should note that the quantum energy of an MW field at 3 GHz corresponds to change in energy of thermal movement in response to a 1°C increase in temperature.

The possibility is not excluded that heating occurring during irradiation disturbs the order created by the field. A situation of this sort is observed in thin superconducting bridges irradiated by an SHF field (88). In the case of unidirectional action of temperature and a field, the effect of heating simply exceeds the field effect (for example, inactivation of enzymes by a high-power SHF field). Thus heating of the object during irradiation prevents observation of the biological effect caused by the direct (electromagnetic) influence of microwaves.

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STIMULATORY ACTION OF AN ELECTROSTATIC FIELD ON DEVELOPMENT OF A *Candida tropicalis* CULTURE

ELEKTRONNAYA OBRABOTKA MATERIALOV in Russian No 3, 1978 pp 66-67

[Article by V. P. Kradenov]

[Text] A number of works have been published (1-5) devoted to research on the action of electric current and electric fields on development of microorganisms. They have noted stimulatory (1,2) and inhibitory (3-5) action on the part of these physical factors.

Jointly with M. Kh. Shigayeva and L. V. Rodionova the author studied the action of an electrostatic field on development of a 2-3-day culture of *Candida tropicalis*, strain SK-4, depending on field intensity.

Petri dishes holding a yeast suspension were place on a grounded electrode, and high voltage from a direct current source was fed to the second electrode. Field intensity varied from 1 to 7 kv/cm. Suspension treatment times were 3, 10, and 1,200 seconds. A suspension not exposed to the electrostatic field served as the control. The survival of yeasts was determined in accordance with the commonly accepted technique 6-8 times. We obtained data by a fractional method. The dependence of the survival of feed yeasts on field intensity is shown in the table below.

Analysis of the obtained data showed that when suspensions are treated for 3 seconds, an inhibitory effect is observed at all studied field intensities. Lengthening of the treatment time to 10 seconds led to stimulatory action of the electrostatic field at all intensities, with the exception of 6 kv/cm. The greatest stimulatory effect was noted when the treatment time was increased to 1,200 seconds. At a field intensity of 3 kv/cm the number of cells in the treated suspension increased by more than 14 times as compared to control.

The dependence of the survival of feed yeasts on field intensity is complex, probably because of the following. We know (6) that when distilled water is subjected to a magnetic field, its electrical

Dependence of the Survival of Feed
Yeasts on Electrostatic Field Intensity
(% of Control)

Время обработки суспензии, с (1)	(2) Напряженность поля, кВ/см						
	1	2	3	4	5	6	7
3	67,39	26,08	53,69	30,43	73,9	28,26	63,04
10	290,9	318,18	200,0	254,5	481,8	81,8	263,4
1200	66,6	783,3	1466,6	226,6	783,3	41,6	1025,0

Key:
1. Suspension treatment time, sec
2. Field intensity, kv/cm

conductivity, viscosity, and surface tension change. It has been established that the electrical resistance of water can increase by 2-3 times in response to change in magnetic field intensity, the dielectric permeability of water changing just as much.

Our preliminary experiments on electrical resistance of feed yeast suspensions subjected and not subjected to an electrostatic field also demonstrated that electrical resistance of the suspension changes following treatment in the field. This obviously has an influence on the effectiveness of its action as well.

We also studied the effect of exposing a suspension to an electrostatic field on cell growth dynamics and accumulation of feed yeast biomass Suspension treatment time in the field was 300 seconds, and the field's intensity was 6 kv/cm. An untreated suspension served as the control. The yeasts were cultured in synthetic Rieder medium containing 1 percent glucose in a rocker at 180 rpm and 29-30°C. Yeast cells were counted under a microscope in a Goryaev chamber, and biomass accumulation by weight was determined in accordance with the commonly accepted technique.

Analysis of the dependencies in figures 1 and 2 showed that intensive cell growth occurred in the first 6 hours following treatment in an electrostatic field, in comparison with the untreated suspension. Later (8-12 hours) the quantity of cells in the control culture basically increases over the quantity in the culture subjected to electrical treatment. However, 24 hours following the start of culturing the quantity of cells in the electrically treated culture exceeded the quantity of cells in the control culture by three times.

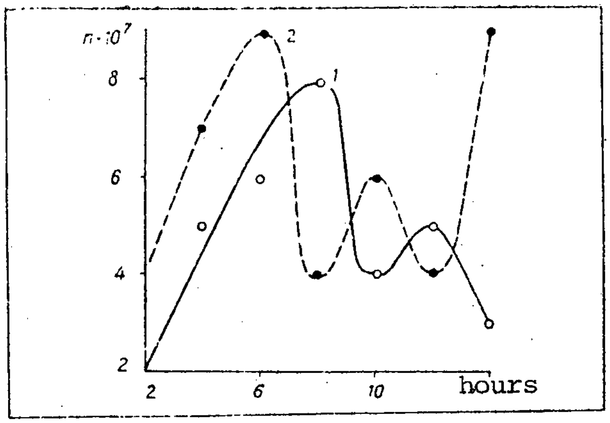

Figure 1. Effect of Electrostimulation on Cell Growth Dynamics: *1*--control; *2*--with electrostimulation

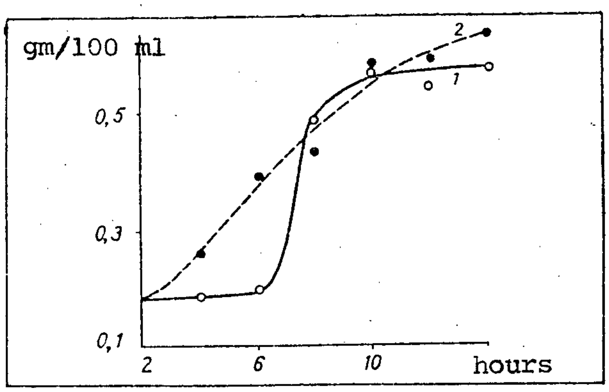

Figure 2. Effect of Electrostimulation on Biomass Accumulation Dynamics: *1*--control; *2*--with electrostimulation

A similar pattern was observed for accumulation of feed yeast biomass. As an example, 6 hours after the start of culturing the electrically treated culture accumulated twice more biomass than did the control culture. The difference of growth of feed yeast biomass in the control and experimental cultures can be explained in our opinion by the fact that growth of biomass in the control culture proceeds in the conditions of substrate inhibition, while in the experimental culture it proceeds in the conditions of inhibition by metabolic products (7).

Our experiments indicate that treatment of feed yeast suspensions by an electrostatic field can produce both an inhibitory and a stimulatory effect depending on the treatment conditions.

The optimum stimulatory conditions promoting cell growth and accumulation of feed yeast biomass are an electrostatic field with an intensity of 3 kv/cm and a treatment time of 1,200 seconds.

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BIOMEDICAL EFFECTS OF MILLIMETER RADIO WAVES

Odessa OFTAL'MOLOGICHESKIY ZHURNAL in Russian No 3, 1978 pp 187-190

[Article by Prof I. S. Cherkasov and students V. A. Nedzvetskiy and A. V. Gilenko, Department of Eye Diseases, Odessa Medical Institute imeni N. I. Pirogov]

[Text] Research on and revelation of the possibilities for practical utilization of electromagnetic oscillations--extremely high frequencies (EHF) represented by millimeter radio waves (MMW)--is acquiring especially important significance today (6,25).

Biological research conducted in the millimeter range since 1965 has revealed, in addition to the possible injurious action of MMW on the body at high intensity or with long exposure (2,3,9-11,17) and the capability of MMW at low athermal intensities for stimulating cell division in plants (18), in isolated cell cultures (12), and in microorganisms (6,23), the ability to heighten the activity of proteolytic enzymes (15) and the resistance of erythrocytes to the effect of low temperatures (13) and to promote a decrease in staphylococcal infection in wounds (1).

Researchers have also been attracted many times to the phenomenon of resonant MMW absorption by water vapor and by oxygen molecules (19,27). The acutely resonant nature of MMW absorption was also observed in biological systems (7,21,22), which is explained by coincidence of the characteristic frequencies of water of hydration and free water and of some tissue protein molecules with the frequency of the acting field (14,16).

At the same time the opinion exists that MMW are totally absorbed by outer body coverings, such that they do not penetrate into the organism (26).

Considering that MMW are different from all other types of electromagnetic emissions, it appeared promising to experimentally study the specific features of the action of athermal intensity MMW on body tissues, primarily on the organ of vision, which is one of the most sensitive organs in relation to electromagnetic waves.

The goal of the present work was to study the effect of MMW on both the normal cornea and a cornea subjected to mechanical injury, and on the specific nature of the healing of an injured cornea.

Materials and Methods

The experiments were conducted on adult rabbits in seven experimental and three control series. In all, 248 experiments were performed.

The 48 animals in series 1 were subjected to local radio emissions on the right eye with exposure times of:

Group 1A (12 animals)--10 min;
group 1B (12 animals)--30 min;
group 1C (12 animals)--60 min;
group 1D (12 animals)--100 min.

Total planar cornea preparations stained with halocyanin-chromium alum were prepared immediately after irradiation and 1, 3, 6, 12, and 24 hours after irradiation; these preparations were used to determine the mitotic index (MI) of the epithelial layer and to assess structural characteristics.

Control series 2 (12 animals) underwent all stages of the experiment with the exception of the exposure to MMW.

In series 3 (64 animals) a standard linear cut was made under local anesthesia in the corneas of both eyes, 5 mm long, damaging the epithelium and part of the cornea itself; the right eye was subsequently subjected to a 1-time 30-minute MMW exposure, and the rate of disappearance of defects in both corneas was measured in accordance with the procedure suggested by Ponomareva-Astrakhantseva (20), as modified by us.

Series 4 (12 animals) was a control--that is, it was not subjected to MMW.

In series 5 (8 animals) the experiments were conducted with the rabbit's body completely shielded, except for the irradiated region of the right eye, by a grounded material opaque to radio waves.

After standard injuries were inflicted on both corneas, the 26 animals in series 6 were subjected to local radio wave irradiation in the occipital area.

In series 9 (12 animals) the animals were not exposed to MMW following infliction of injuries on the corneas and skin; this served as a control series.

In a separate series, series 10 (30 animals) the eyes of intact animals were subjected to local irradiation with the intensity and exposure time increased correspondingly by 4 and 3 times; moreover the animals were exposed daily for 10 days, after which their overall condition and the condition of media in the visual organs of irradiated animals were kept under clinical observation for 1 year.

The animals were exposed to MMW produced by an integrated device designed by us--the Rezonans; the parameters of the procedure we suggested were strictly defined in this case.

An ophthalmological micro-macromanipulator was used to ensure that the corneal injuries would be standard and identical (24).

A 2 percent lidocaine solution was used as the local anesthetic, since it does not have a significant effect on wound healing rate (4).

A fluorescence test, ophthalmoscopy, and biomicroscopy were employed to monitor healing of the defects and the condition of eye media; this was done prior to the research, after injury of the cornea, immediately following exposure to MMW, 30, 60, 90, 120, and 180 minutes after exposure, 4, 5, 6, 7, and 8 hours after exposure, and 1 day, 1 month, and 1 year after exposure to radio waves.

During the time of radio wave exposure, in all cases we implemented a complex of measures aimed at preventing contamination of the experiments by fluctuating phenomena stemming from the biotropic action of electromagnetic cosmic forces--electromagnetic emissions of cosmic and terrestrial origin, variations in the Earth's electric and magnetic fields, and solar activity.

Research Results

Comparative study of total planar preparations of the corneas of control and experimental animals did not reveal abnormal deviations in the morphological structure of corneas exposes to MMW.

However, computation results revealed a difference in the mitotic activity (MA) of the epithelium of irradiated, nonirradiated, and control corneas. An exposure time of just 10 minutes caused an increase in the quantity of dividing cells in the irradiated cornea--MI = 16±1, while cell division remained normal in the nonirradiated cornea of the same animal--MI = 11±1 (MI_C = 11±1). The MA increased even more with an exposure time of 30 minutes: For the irradiated eye, MI = 25±2, and for the nonirradiated eye, MI = 15±1. An exposure time of 60 minutes caused an increase in the quantity of mitoses up to 53±3 and 25±2 in the irradiated and nonirradiated corneas respectively.

The increase in the MA was found to be most highly pronounced with an exposure time of 100 minutes; in this case the number of dividing cells attained 107±7 in the irradiated eye and 40±3 in the nonirradiated eye of the same animal, as opposed to 11±1 in control.

In all cases the MA attained its maximum 1 hour following termination of radio wave exposure. The MI subsequently decreased smoothly; it did not drop below the initial value, but it did reach the initial level 24 hours following termination of MMW exposure. Pathological mitoses were not revealed in the preparations.

Significant acceleration of wound healing was discovered following irradiation of injured cornea. While elimination of the defect and complete epithelialization of the cornea were noted 8±0.5 hours following injury in control animals, highly stable healing occurred in 3±0.5 hours among animals exposed to MMW.

When the animal was shielded by a material opaque to radio waves elimination of the defect was accelerated as well, but the acceleration effect was lower than in the cases of MMW exposure without shielding, being 5±0.5 hours.

It was discovered that when one eye was subjected to local irradiation, healing of the nonirradiated eye was also accelerated, and elimination of the defect was only 1 hour (±0.5) behind healing of the cornea subjected to radio waves.

Special mention should be made of the fact that injuries on both corneas healed simultaneously following radio wave exposure of the occipital area. This procedure reduced the defect elimination time from 8±0.5 hours to 1±0.5 hours.

Surveillance of the condition of eye media (cornea, lens, fundus opticus) and observation of the general condition (behavior, sleep, cardiac and respiratory activity, appetite, weight) of animals exposed to MMW did not reveal any sort of abnormal deviations in a period of 1 year.

Discussion of Results

The results indicate that when MMW interact with the body, a situation can be created in which this range of waves has a pronounced therapeutic effect; in particular reparative regeneration becomes significantly accelerated and highly stable. The nature of the therapeutic effect of MMW depends not on the amount of energy absorbed by tissues but rather on wavelength, irradiation time, precisely which body systems are irradiated, and the irradiation conditions.

Research by D. S. Chernavskiy et al., (1967,1973), who studied superhigh frequency oscillations of enzyme molecules arising in connection with their elastic deformations, shows that the frequency of the intrinsic oscillations of a proteinaceous enzyme has the same order of magnitude as does the resonant frequency in the spectrum of action of MMW. Presence of such processes opens up the possibilities for using MMW for resonant control of biochemical processes and for regulation of enzymatic reactions (5).

The acutely resonant nature of interaction between MMW and the body was confirmed in our research in all cases of radio wave exposure; the slightest change in the parameters of the effect, for example shifting of the wavelength by 0.005 mm (!) caused change in the therapeutic effect, increasing or decreasing it. Thus when the optimum exposure conditions are selected strictly, MMW are a biologically adequate factor capable of creating the effect of resonant radio-control of the source of biological processes in both healthy and damaged body tissues.

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NEW SCIENTIFIC BRANCH ESTABLISHED FOR ELECTROMAGNETIC HYGIENE STUDY

Moscow OKHRANA TRUDA I SOTSIAL'NOYE STRAKHOVANIYE in Russian No 6, 1978 p 27

[Article by A. Appenyanskiy, director of the Electromagnetic Hygiene Laboratory of the Sanitary-Epidemiological Station]

[Text] Electromagnetic Hygiene. This is the name of a new branch of hygienic sciences: it studies the effect of continuous (electric and magnetic) low frequency and radio frequencies on man, as well as infrared, ultraviolet and visible spectrum radiation.

The nature of these fields and radiations is varied. Thus, in particular, a continuous magnetic field is generated around a wire which carries a constant current as well as in the vicinity of natural magnetic materials. An electrostatic field is produced by charged bodies, for example, those which have been charged by dielectric friction, by loose substances and by some liquids. The passage of an a.c. current through a wire produces an alternating magnetic field. When a body is heated to a certain temperature, then visible spectrum radiation takes place. A concrete monochromatic radiation can be obtained with the use of special apparati (optical quantum generators-lasers).

The wide application of electromagnetic fields and radiation in industry has made it necessary to maintain some hygienic and health control over the way that these are used, given that under certain conditions they may have a harmful effect on people who come into contact with them in their work. In general, their biological effect is on the regulatory systems of the organism--the nervous and endocrine systems--which in the final result leads to the development of vegetative-vascular disorders. In addition, in each case, certain systems and organs can be shown to be more sensitive to this factor. The effect of laser radiation, super-high frequency radiation and ultraviolet radiation, for example, shows up most often as damage to the eyes and skin.

Today various health safety standards and regulations exist or are in the process of being developed which regulate the use of most electromagnetic fields for industrial, medical, scientific and other purposes.

In 1977 health regulations No 1757-77 were established for working with electrostatic fields, health regulations No 868-70 were established for electrical fields of industrial (50Hz) frequency, and health regulations No 848-70 for radiowaves, as well as GOST 12.1.006-76.

Health regulations No 1042-73 define the permissible levels of infrared (heat) radiation. For artificial light, the levels are determined by SN No 245-71, as well as by the SN and P chapter P-A . 9-71.

In order to avoid an ultraviolet deficit, the "Guide for the Planning and Exploitation of Sources of Artificial Ultraviolet Radiation" (No 1158-74) was developed.

In 1972 the first health standards for work with lasers were published.

The strict adherence to these regulations and standards completely excludes the possibility of any harmful effect of electromagnetic fields on man.

We will now attempt to answer several questions of general interest which have come up in the letters of the readers of this magazine.

Workers of the "Armavir-330" substation of the Armavir electrical network, who, due to the nature of their work, are under the effect of high voltage transmission lines and charged units within the substation, would like to know about the negative consequences of man's exposure to an electrical field of 50Hz with a voltage of more than 5 kV/m.

Let us note that the question itself is not quite accurate. In the current "Norms and Regulations for Work Safety at Substations and Electric Transmission Lines" approved by the Ministry of Health of the USSR, personnel are protected from any harmful effects either by a decreased electric field or by a decreased time of exposure (exposure to a field of 5kV/m is acceptable for the working day period; exposure to a field of 10kV/m for not more than 3 hours at a time, and so forth). Therefore, an exposure to a fairly intense field, as long as it is within the permissible period of time, is not harmful to man.

In some cases it is necessary to use special protection (stationary or portable) or individual protection (headgear, suit, shoes). These measures lower the field which affects man to 5 kV/m and less. The knowledgeable use of these protective measures can make the work completely safe.

Some comrades would like an explanation of the system of privileges for those workers who are subject to the effects of electromagnetic waves and radiation.

Privileges are granted only in those cases when it is impossible to ensure completely harmless working conditions. Addenda to "A Listing of the Industries, Professions and Duties with Harmful Working Conditions" can be made by the ministries of the USSR and by the Soviets of Ministries of the Union Republics by agreement with the USSR State Committee on Work and Social Questions, All-Union Central Trade Union Council, and the Ministry of Health of the USSR.

Comrade Oksimets, Head Engineer of a Donetsk candy factory asks how to combat electrostatic charge.

In order to get rid of electrostatic charge special neutralizers are widely used (aero-ionizators) which humidify the air in the working environment. In cases when this is not sufficient special clothing made from natural cloth and special footwear can be worn. In some cases charge removers in the form of bracelets are worn.

Doctor Bubyashov form the city of Ryazan' is interested in the norms for static electricity. In the Riga Medical Institute, the "Sanitary-Hygienic Norms of Permissible Limits of Electrostatic Field Voltage" (No 1757-77) were worked out and accepted by the USSR Ministry of Health.

The correct application of the sanitary norms and regulations worked out by hygienists protects the worker from the harmful effects of electromagnetic fields.

/Photo Caption/ In the All-Union Central Scientific-Research Institute for the Protection of Work of the All-Union Central Trade Union Council experiments are being conducted with the goal of developing concrete recommendations which would prevent the harmful effects of laser radiation on man. On the photo: Director of the Laboratory for Radiation Safety, Doctor of Technical Sciences, E. Chistov, during an experiment. (Photo by V. Koshevoy, TASS).

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THE COMBINED EFFECT OF AN SHF FIELD AND AN UNFAVORABLE MICROCLIMATE ON THE BODY

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[Article by V. A. Zhuravlev]

[Text] Reports have been published concerning the great expressiveness of functional changes occurring in the bodies of people working in the presence of the concurrent action of SHF [superhigh frequency] energy and high ambient air temperature (A. Ya. Loshak, 1965; Boiteau, 1963, etc.). Deichmann et al., (1959) noted accelerated death of animals exposed to an intense SHF field when radiation is combined with high air temperature.

The objective of our work was to establish the effectiveness of the integrated action of microwaves of nonthermal intensities and combinations of individual microclimatic factors encountered in real conditions (N. F. Koshelev, O. N. Karelin, 1966, etc.). The research was conducted on young female rats that had reached a weight of 155-160 gm by the beginning of the experiment. Animals in the first (experimental) group were irradiated daily for 1 hour by microwaves in the 10 cm range at a power flux density of 5 mw/cm^2, after which they were placed in a thermostat at an air temperature of 40° and a relative humidity of 22-25 percent. Air movement did not exceed 0.05 m/sec, and the mean radiation temperature was 40.5°. The second group of rats was exposed to an unfavorable microclimate alone in the thermostat under the conditions indicated above, after which they were left in individual cages for 1 hour without irradiation. The control group of animals was exposed to neither SHF radiation nor heat. All other experimental conditions were the same. The total time of exposure was 60 days; after this, the rats were paired with healthy males, and reproduction was observed. Weight dynamics and a number of blood indices were studied during the experiment, and the morphological pattern of some internal organs was investigated at end of the experiment.

The experiment showed that exposure of rats to the unfavorable microclimate caused a significant rise in rectal temperature, this increase being most pronounced in response to the combined effect. Thus while temperature remained at the initial level (38.4-38.6°) following irradiation, it increased to 40.1-40.4° after heating in the thermostat. The rectal temperature of rats in the second group was 39.8-40.2° after heating. All animals in both experimental groups were sluggish and wet when they left the thermostat. Their weight did not differ significantly from that of control animals ($P > 0.05$).

An increase in the number of erythrocytes and in hemoglobin concentration were noted in peripheral blood (Table 1) taken from veins in the tails of rats in the first group; the second group exhibited only a tendency toward growth in the number of erythrocytes, the hemoglobin concentration not differing from control. On the other hand, the leukocyte count increased among animals in the second group, differing little from the control figures following combined action of microwaves and heat. The proportionate weight of blood underwent practically no change in all groups, though a slight tendency for its decline was noted in response to the combination of factors and for its growth in response to heat alone were noted. A decrease in blood viscosity was more pronounced in response to the combination of microwaves and high temperature. The slight decrease in proportionate weight and the pronounced decline of the viscosity of blood could probably be explained by the specific effect of an SHF field on the body's protein-forming system. In the opinion of Schliephake (1960), an increase in hemoglobin and a decline in blood viscosity are associated with disturbance of liver functions in response to microwave radiation. Blood catalase activity decreased in both experimental groups, though more distinctly in the first.

Reproduction data are interesting from my point of view. Thus the percentage of reproducing females was rather high in the control and second experimental groups--87.5. It was lower in the second group--50 percent. The number of rats in a litter was also lower for this group (Table 2).

The sex ratio (males to females) in litters produced by animals exposed to harmful effects has certain significance. In particular, V. L. Rassel (1960) cites Parks and Gertvig, who observed a dominance of males in the progeny of mice exposed to roentgen radiation. Rat litters were dominated by females in ordinary conditions--54.4-56 percent (P. P. Gambaryan et al., 1955). According to my data the ratio of sexes in the control group agreed with the natural indices, while a dominance of females was noted in the experimental groups.

Analysis of the internal organs of killed animals revealed more highly pronounced changes in rats of the first group. The weight coefficients of the liver and spleen were significantly lower than in control, while significant deviations were not revealed among animals in the second group (Table 3).

The histological pattern of changes in cardiac muscle and in liver, kidney, and spleen tissue stained with hematoxylin-eosin was mainly distinguished

Table 1

(1) Характер воздействия		(2) Эритроциты в млн.	(3) Гемоглобин в г%	(4) Лейкоциты в тыс.	(5) Удельный вес в г	(6) Каталазное число	(7) Вязкость крови
СВЧ и нагревание в термостате (8)	(9) Количество	5,41	14,8	11385	1,048	4,6	4,3
	t	2,2	2,4	0,3	0,7	9	6
	P	<0,05	<0,05	>0,05	>0.05	<0,001	<0,001
Нагревание без облучения (10)	(9) Количество	5,28	15,4	13975	1,052	5,2	4,9
	t	1,85	0,2	2	0,9	4,3	—
	P	>0.05	>0,05	0.05	>0,05	<0.001	
Контрольная группа (11)		4.86	15.5	11050	1,05	5.8	4,9

Key:

1. Nature of effect
2. Erythrocytes, millions
3. Hemoglobin, gm-percent
4. Leukocytes, thousands
5. Proportionate weight, gm
6. Catalase number
7. Blood viscosity
8. SHF and heating in a thermostat
9. Quantity
10. Heating without irradiation
11. Control group

by the degree to which dystrophy was pronounced, inasmuch as the same sorts of deviations were encountered in both experimental groups. However, differences also existed in the nature of morphological changes. Thus in cardiac muscle, homogenation and fragmentation of muscle fibers coupled with minor subepicardial hemorrhaging were noted more frequently in response to the combined action of the factors, while circulatory disturbances (plethora, stromal edema, and so on) dominated in the group subjected to heating alone. Signs of chronic venous plethora, more highly pronounced in response to the combined action of microwaves and heat, were detected in the liver and spleen. The degree of fat dystrophy in the liver (Sudan-IV staining) was moderately expressed in both control groups. The extent of kidney tissue dystrophy was highly insignificant.

Analyzing the obtained data, we can say that combination of an SHF field with an unfavorable microclimate causes pronounced functional changes in the bodies of animals, as well as a rise in the degree of dystrophic changes experienced by some organs. This can be seen from the increase in erythrocytes and hemoglobin and the dramatic decline in catalase activity and blood viscosity. Finally, it was found from an investigation of reproductive

Table 2

Характер воздействия (1)	Количество родивших самок в % (2)	Среднее количество крысят в помете (3)	Соотношение самцов и самок в % (4)
СВЧ и нагревание в термостате (5)	50	6,5	53,9:46,1
Нагревание без облучения (6)	87,5	8,9	56,4:45,6
Контрольная группа (7)	87,5	8,7	44,2:55,8

Key:
1. Nature of effect
2. Quantity of reproducing females, %
3. Average number of rats in a litter
4. Ratio of males to females, %
5. SHF and heating in a thermostat
6. Heating without irradiation
7. Control group

Table 3

Характер воздействия (1)	Сердце (2)	Печень (3)	Селезенка (4)	Почки (5)
СВЧ и нагревание в термостате (6)	0,39 P>0,05	3,0 P<0,05	0,37 P<0,05	0,65 P>0,05
Нагревание без облучения (7)	0,45 P>0,05	3,37 P>0,05	0,48 P>0,05	0,63 P>0,05
Контрольная группа (8)	0,41	3,42	0,45	0,72

Key:
1. Nature of effect
2. Heart
3. Liver
4. Spleen
5. Kidneys
6. SHF and heating in a thermostat
7. Heating without irradiation
8. Control group

functions that the number of females born and the number of rats in a litter were significantly lower in the first group than in the second. Despite the great thermal load, the reproduction indices of the second group did not differ from control; this result can be explained by absence of specific influence on the part of an SHF field.

Clarification of the integrated effect of an SHF field and an unfavorable microclimate on the body has practical significance to prevention of radio-wave injuries and development of standards on combined effects. On the other hand changes I revealed in the bodies of animals heated in a thermostat show that we must account for the tremendous role played by overheating in development of various functional disturbances, and that we must first of all reduce the temperature of air and surrounding surfaces in work areas to optimum levels by installing effective thermal insulation or air conditioning systems.

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WHEAT GROWTH IN CONSTANT MAGNETIC FIELDS

Kiev DOPOVIDI AKADEMIYI NAUK UKRAINS'KOYI RSR, Series B in Ukrainian No 4, 1978 pp 351-354

[Article by N. I. Bogatina, B. I. Verkin, V. A. Kordyum, Ye. L. Kordyum and V. M. Litvin: "Effect of constant magnetic fields of various directionality on the growth rate of wheat sprouts"]

[Text] Researchers have begun to pay more attention to the effect of constant and variable weak magnetic fields [1-6] (with earth-like field intensity) on diverse biologic objects. Research findings in this field are contradictory mainly because of the insufficient purity of the experiment from the viewpoint of physics, inadequate selection of biological objects and parameters of the effect in question. Thus further experimentation in this field has not lost its novelty and urgency.

The biological objects of our study were wheat sprouts (Mironovskiy 808, 1976 crop, 98% yield in early germination up to 5 days) at 23°C. Temperature within one test run was stable with average deviation of ± 0.5°C.

The grains sprouted on a thin cotton ball in Petri dishes. They were set on the cotton without pre-moistening: all grains in one Petri dish were oriented to one side and then a certain quantity of water was infused into the dish.

The grains sprouted in the dark in a man-made magnetic field of a certain bearing. The Earth's magnetic field was screened with double-hinged ferromagnetic screens with a flat bottom made of permalloy which had been pre-magnetized and heated at high temperature. The screen's net magnetic field was as follows: horizontal component (H_{hor} = 0.2 mOe) and vertical (H_{vert} = 0.5 mOe). Variation in the net magnetic field in the screen during the experiment did not exceed 0.07 mOe.

The man-made magnetic field was created with solenoids placed within the screen; its uniformity in the volume occupied by the Petri dishes was 1%. Instability of the artificial magnetic field in the screens did not exceed 0.1 mOe; the regular variation of the artificial magnetic field with time was 0.1-1% of its value.

The length of the roots and sprouts of wheat were measured. Table 1 illustrates data of the control grains which were placed in the residual magnetic field of the screen and test grains which were placed in the horizontal artificial magnetic field (the magnetic field generated in the Petri dish—in the location of the roots— was perpendicular to the field of gravity. Test grains were also placed in a man-made vertical magnetic field (magnetic field directed parallel to the gravitational field along the sprout, perpendicular to the surface of the dish containing the roots). The relative juxtaposition of grains in the dishes and the magnetic field vector are shown in Figure 1.

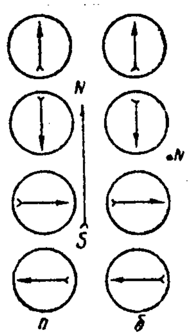


Figure 1. Orientation of wheat grains with respect to the magnetic field vector. Arrows inside dishes indicate orientation of grains; dishes are oriented with respect to the external magnetic field.

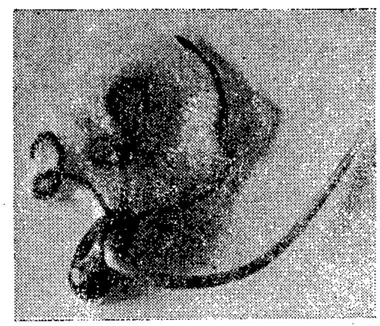
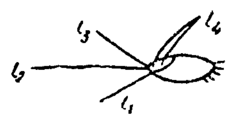


Figure 2. Wheat sprouts placed in magnetic field of variable polarity.

Each figure in Table 1 is an average quantity adopted for 125 grains; rms deviation does not exceed 5-8% (reliability is 95%). As this table suggests, a horizontal magnetic field substantially alters the growth pattern of grains whereas a vertical field has no such effect.

This is probably associated with the fact that the effect of gravitational forces is too strong in the vertical magnetic field. Furthermore, during the experiment (5 days) the sprouts did not adapt to the absence of a magnetic field.



Номер досліду a	Його тривалість, доби b	c $H_{гор}$=0,2*		d $H_{верт}$=0,5		c $H_{гор}$=0,5		d $H_{верт}$=0,5	
		l_1	l_2	l_3	l_4	l_1	l_2	l_3	l_4
1	4	4,8	6,3	4,1	4,1	8,8	13,7	8,4	7,9
2	3	3,3	5,1	3,2	3,0	8,9	13,9	9,7	8,3
3	4,5	8,8	11,9	9,0	8,1	23,4	31,1	23,0	22,1
4	2,5	1,2	2,9	1,0	1,3	4,9	6,3	4,4	4,3
5	3	1,3	3,3	1,2	1,4	9,2	13,8	9,5	7,3
6	3,5	—	—	—	5,0	—	—	—	6,7
7	4,5	15,0	18,8	14,6	12,8	16,7	22,6	16,7	17,9
8	4	9,3	11,2	8,8	7,6	13,2	15,4	12,8	11,3
		$H_{гор}$=0,2		$H_{верт}$=0,5		$H_{гор}$=0,2		$H_{верт}$=0,5	
9	5	—	—	—	5,0 N S ↑	—	—	—	—
10	4,5	15,0	18,8	14,6	12,8 S	11,3	18,5	10,2	11,5
11	3,5	—	—	—	5,0 N ↓	—	—	—	4,6
12	4,5	15,0	18,8	14,6	12,8 N S ↑	10,2	14,7	10,0	10,6
13	4	15,3	20,5	15,0	12,1 S	15,2	20,4	16,7	13,6
14	4	15,3	20,5	15,0	12,1 N ↓	13,3	19,1	13,2	11,5

Table 1. Effect of horizontal and vertical magnetic fields on the growth rate of wheat grains, in millimeters.
[Key: a) test number; b) duration, in days; c) horizontal; d) vertical.] *Field is expressed in me in all cases.

It is worth noting that roots which sprouted on the cotton grew only in one area of the dish and coleoptiles were first in the same area; they later were directed at an angle to the dish surface (curvature) and then in the vertical plane. This may be why all effects are much less clear in the roots than in the coleoptiles.

The next experiment was based on the various orientation of grains with respect to the horizontal magnetic field. The results are given in Table 2, whence it is clear that the orientation of grains with the bud to the south greatly accelerates (by 44%) the growth of grains (magnetotropism). Results obtained in the residual magnetic field of the screen are given for comparison in TAble 2 (magnetotropism is absent here).

In addition, we should note that under conditions of varied orientation of the bud with respect to the magnetic field (east and west), the ratio of lengths of roots l_1 to l_3 is changed: the roots which does not have to turn to the north becomes longer since it is already aimed in that direction. In most cases the roots grow in the southward direction re-

TABLE 2. Effect of Relative Orientation of Bud and Horizontal Magnetic field on rate of growth of wheat sprouts

a Орієнтація зародка відносно магнітного поля	b Середня з 7 дослідів довжина колеоптилю	c Залежність видів видовження колеоптилю по відношенню до північного напряму
d Північ	$L_w=10,3$	$\frac{L_n-L_s}{L_n}=44\%$
e Південь	$L_s=14,8$	$\frac{L_n-L_e}{L_n}=5,6\%$
f Схід	$L_E=10,0$	
g Захід	$L_w=9,6$	$\frac{L_n-L_w}{L_n}=6,8\%$
h У залишковому магнітному полі		
Північ	$L_n=6,2$	
Південь	$L_s=6,4$	
Схід	$L_E=6,7$	
Захід	$L_w=6,2$	
i При орієнтуванні зародка на		
Схід	$l_1>l_3$	
Захід	$l_1<l_3$	
Південь і північ	$l_1\approx l_3$	

[Key: a) orientation of bud with respect to magnetic field; b) average length of coleoptile in 7 tests; c) coleoptile elongation as a function of southward orientation; d) north; e) south; f) east; g) west; h) in residual magnetic field; i) with bud orientation towards...].

TABLE 3. Effect of Relative Orientation of Bud and Strong Horizontal Field on Rate of Growth of Wheat Sprouts

a Орієнтація зародка відносно магнітного поля і його величина	b Середня довжина коренів і проростків, мм; $n=4$			
	l_1	l_2	l_3	l_4
South H=2570 Oe	23,2	21,9	23,2	20,7
North H=2570 Oe	15,2	14,2	14,9	13,6
West H=1080 Oe	9,3	12,3	9,8	8,8
East H=1080 Oe	15,5	20,2	14,4	14,5

[Key: a) orientation of bud to field and intensity; b) average length of roots and sprouts, mm]

The next test demonstrates this. Figure 2 shows a wheat sprout which was located in a magnetic field whose polarity was changed every 8 hours. Figure 2 shows that roots, especially central ones (aimed along field), grow with bearing of external field.

Tests with high intensity magnetic fields (H = 2570 Oe) showed analogous results; the only exception clearly observed was the inhibition of root growth directed along the field displayed by the central root (Table 3).

Hence, experiments conducted in magnetic fields ov different intensity (from 20 mOe to 3 kOe) are of interest. They should indicate the role of the magnetic field as a purely informational factor or as an engineering factor whose value substantially affects the quantitative nature of this effect.

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